

STUDY ON WATER DISTRIBUTION MEASUREMENT IN SAND USING SOUND VIBRATION

T.Sugimoto, Y.Nakagawa, T.Shirakawa, and M.Sano

*Faculty of Engineering
Toin University of Yokohama
Yokohama, Japan*

M.Ohaba, and S.Shibusawa

*Faculty of Agriculture
Tokyo Univ. of Agriculture and Technology
Tokyo, Japan*

ABSTRACT

Because the global shortage of water is expected, saving water of the agriculture water is necessary. Therefore, the irrigation method using the minus pressure difference of soil water attracts attention for saving water. This method has the nature keeping the water content inside the ground. In other words, when there are crops, it is the mechanism which supplies the water content which is same quantity with the water content that it absorbed. However, effective saving water is not able to be performed, because the water distribution in soil is difficult to grasp. Therefore, we propose a method of monitoring and imaging of the water content in the rooting zone using a sound vibration. From the experimental result, we confirmed that the distribution of the propagation velocity of sound was a very effective method to the water distribution which is in the shallow position near the sand surface. Also, in the experiment which used negative pressure irrigation, we confirmed that an approximately real time measurement of the water distribution was possible from the distribution of the propagation velocity of sound. In addition, we confirmed that the horizontal and the vertical directions of the propagation velocity of sound was proportional to the water content from the measurement result of the water sensor in the sand. As a future task, we intend to examine whether our method can apply even in the case that a plant is growing up in soil for gardening.

Keywords: Water distribution, Acoustic vibration, Scanning laser Doppler vibrometer, Water sensor

INTRODUCTION

In recent years, the increase of the population of the world doesn't stop and the United Nations is reporting that the population of the world exceeds seven billion. Also, the abnormal weather occurs in the world each place. By these things, a serious water shortage is caused in a lot of countries. In the purpose of using water, there are daily life water, industrial water and agricultural water. Agricultural water is using about 70 % of all water. Therefore, many studies about the saving of the agricultural water are performed. The irrigation system using the difference of soil water potential as one of the researches attracts attention. This method has the nature to keep water content inside ground constant. However, effective saving water is not able to be performed, because the water distribution in soil is difficult to grasp. Although the electrical detection method and the pF meter are used for the measurement method of water in ground, measuring area of a sensor is very small. Therefore, we propose a method of monitoring and imaging of the water content in the plants of rooting zones using a sound vibration and the scanning laser Doppler vibrometer (SLDV; Polytec Corp, PSV400-H4). Our method is possible to measure a wide area. The underground exploration which used a sound vibration is already done. However, the research which controls Irrigation by measuring the water distribution of the plants of rooting zones using the sound vibration isn't done. This time, we study about the influence to the propagation velocity when changing the volume water content of the water distribution.

THE PRINCIPLE OF MEASUREMENT OF THE WATER DISTRIBUTION

The method of measuring

The schematic figure for water distribution measurement using SLDV and giant magnetostrictive vibrator is shown in Fig.1. SLDV measures the vibration of ground surface excited by sound wave caused from vibration source. Using the vibration waveform and the output waveform calculates the propagation velocity from vibration source to the measurement point. There is a difference in the average of propagation velocity (sand: about 130 m/s, water: about 1500 m/s) in sand and water. When passing water distribution, the propagation velocity is expected to be fast. On the basis of this supposition, water distribution can be estimates.

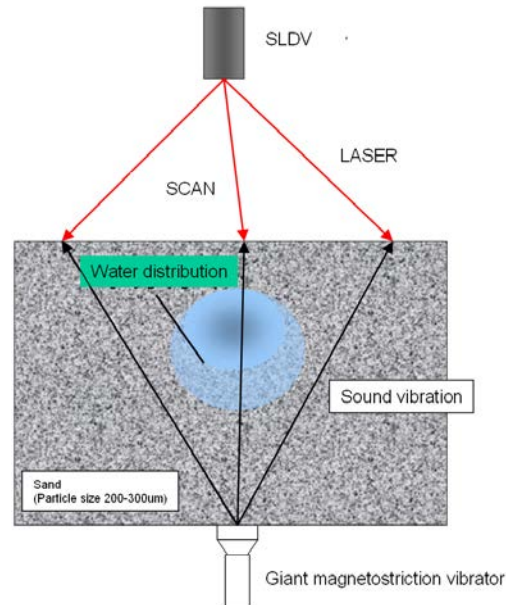


Fig. 1: The schematic figure for water distribution measurement.

The principle of calculation of the propagation velocity

The calculation method of the propagation velocity is shown next. The propagation time and the propagated-distance are necessary to calculate a propagation velocity. It calculates a propagation time using the Hilbert transform. The propagated-distance is a distance from the sound source to the measuring point. Calculation example is shown in Fig.2. First, it looks for the envelope using Hilbert transform. After that, it calculates the time which is taken for the threshold value to the envelope. This time, the difference with the time which was calculated from the output waveform and the vibration waveform is propagation time.

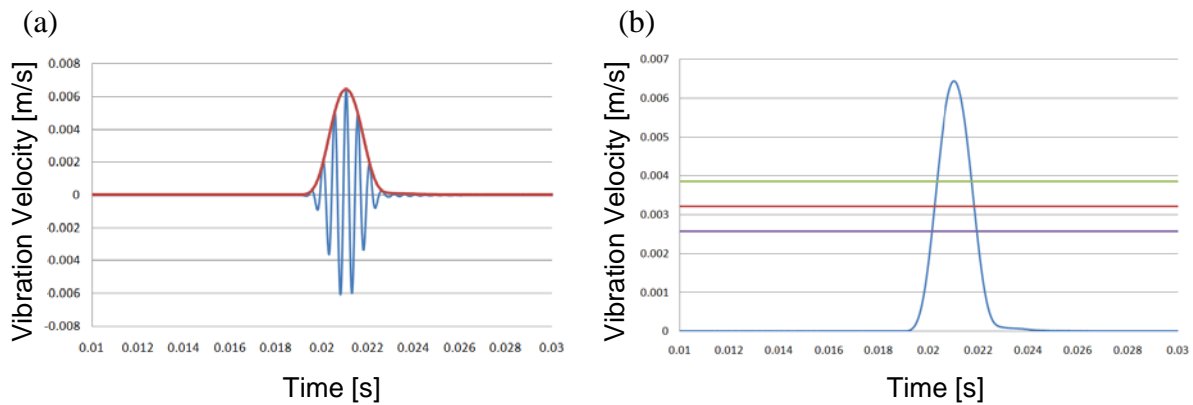


Fig. 2: Examples of the calculation process. a) Hilbert transform, (b) the envelope and the threshold value.

Volume water content

The volume water content is one of the ways to show the water quantity of ground. In this time, we measured the volume water content by two measuring methods. One is measured by soil water sensor (ECH2O probe: decagon device Inc, EC-5) and the other method is measurement of the water-ratio with the soil sample (soil sample method). In this method, the volume water content is computed by multiplying the water-ratio by the true specific gravity of sand after vibration measurement is ended. The true specific gravity of sand is using 2.68 g/cm^3 .

The Relationship between the propagation velocity and the volume water content

We confirmed whether the volume water content and the propagation velocity are proportional. Figure 3 shows an experimental setup. Experiment method is shown as follows. The giant magnetostriction vibrator (Moritex Corp., AA-140J013-MS1) sends vibration from the base of sand which the about 5 cm thickness was wetted and the acceleration sensor that installed in the surface of the sand measures the vibration waveform. After that, we calculate the propagation velocity. A result is shown in Fig.4. From this result, we confirmed that the propagation velocity became fast according to the volume water content.

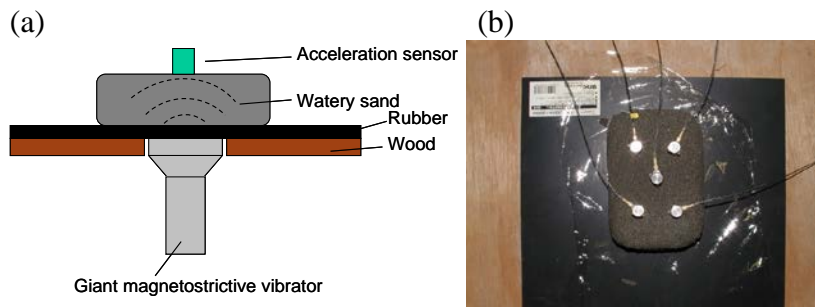


Fig. 3:Experimental setup (The size of the watery soil $10 \times 15 \times 7 \text{ cm}^3$) (a) Experimental setup, (b) the installing position of the acceleration sensor.

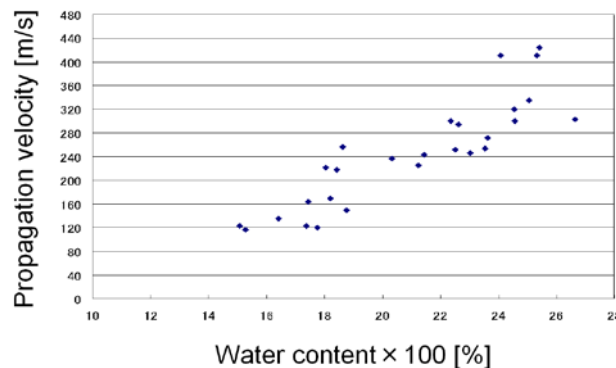


Fig. 4:Propagation velocity vs. volume water content.

THE EXPERIMENT OF THE MEASUREMENT OF THE WATER DISTRIBUTION

Experiment when changing the water content near the sand surface

Experimental setup

Figure 5 shows an experimental setup (The side view of the sand tank). There are nine holes to set up the sound source which was covered with the rubber in the sand tank base. It sends vibration with the giant magnetostrictive vibrator to have installed in the hole of the sand tank base. SLDV measures the vibration of ground surface excited by sound wave caused from vibratory source. The plastic container (40×50×30 cm) which is made from acrylic in the laboratory that had been filled with sand of uniform particle size (200 to 300 μm) was used for this experiment. In this experiment, it measures the status of the water distribution by the change of the vibration propagation. The making method of the water distribution is shown below. First, the plastic container is filled with the sand into the plastic container. Next, the water of the fixed quantity is pour into the container. Finally, a plastic container is removed after having put it in the sand tank upside down. This time, we study that there was a difference in the propagation velocity, when the water-content of the water distribution is 150 ml and 250 ml. Water distribution is installed on the surface of the sand tank and it measured. Experiment method is shown as follows. The output waveform uses the burst wave of 2 kHz of sine wave, 3 cycles. The scan area of SLDV is 17×23 points, the point interval are about 1.75 cm wide and about 1.8 cm long.

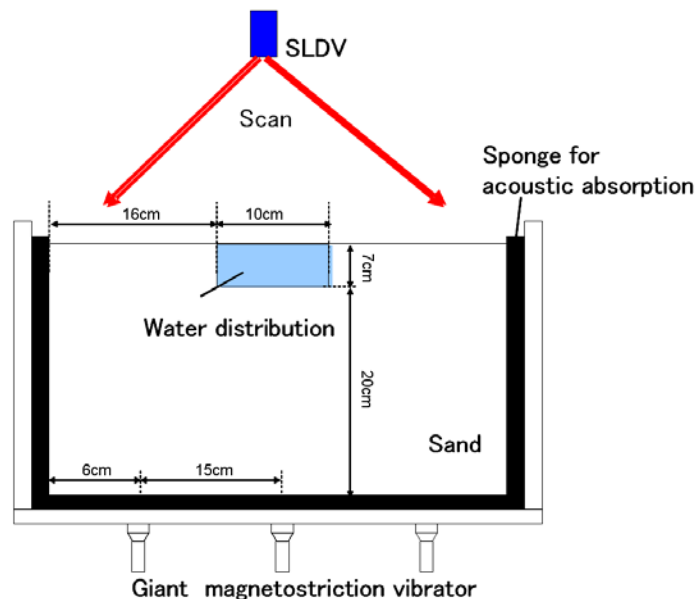


Fig. 5: Experimental setup when installing water distribution in the sand surface.

Experiment result

Result of imaging in the speed of sound range common sound-velocity distribution from 150 m/s to 180 m/s is shown in Fig.6. From this figure, we can confirm that the propagation velocity of 250 ml is faster than 150 ml. The relation between the volume water content and the propagation velocity which was created by using soil sample method and the vibration measurement data of 150 ml, 250 ml is shown in Fig.7. We find that there is a difference between distribution of 150 ml and 250 ml from this figure. We think that the water-content of the water distribution in ground can be estimated by the non-contact using the difference of such a propagation velocity.

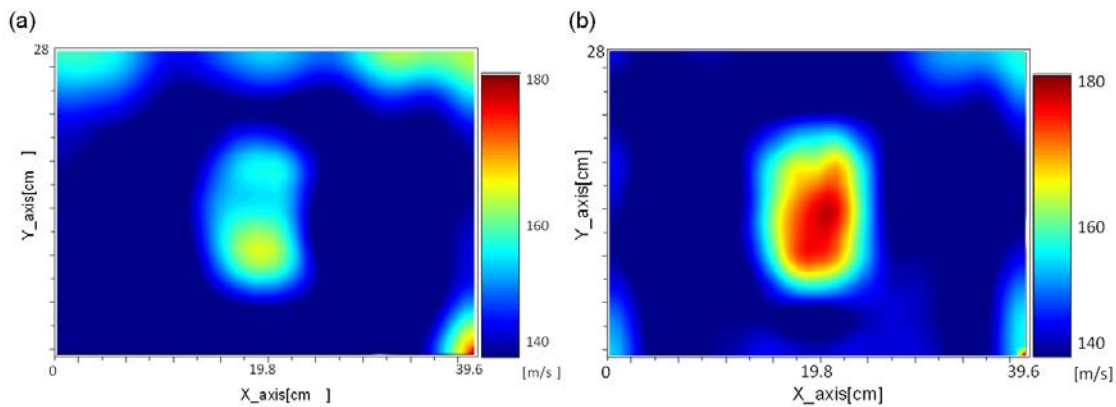


Fig. 6: Result of imaging of sound velocity distribution. (a)150 ml, (b)250 ml.

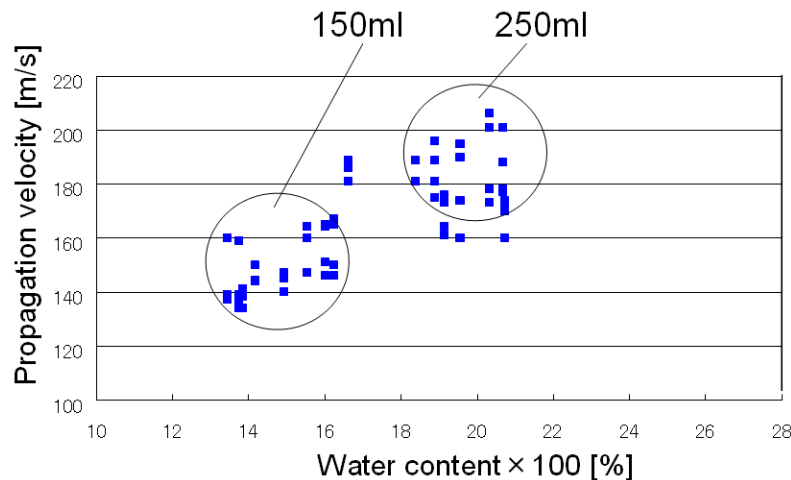


Fig. 7: The volume water content and the propagation velocity.

Water distribution imaging experiment for horizontal direction using negative

pressure difference irrigation system

Experimental setup

Figure 8 shows an experimental setup for horizontal direction when using negative pressure irrigation system. The porous pipe which is made from ceramic is installed in the about 18 cm height from the sand tank base and the level control tank is installed in the position with the low of about 20 cm from the height of the porous pipe. The rate of the water which is supplied to ground by this height is decided. The method of experimenting is same as the method of experimenting to the above. However, this time, the measurement time must be made short because to measure temporally changing water distribution. Therefore, using the sound source position is only under the porous pipe. The vibration measurement measured in the interval of 10 minutes and measured until 90 minutes.

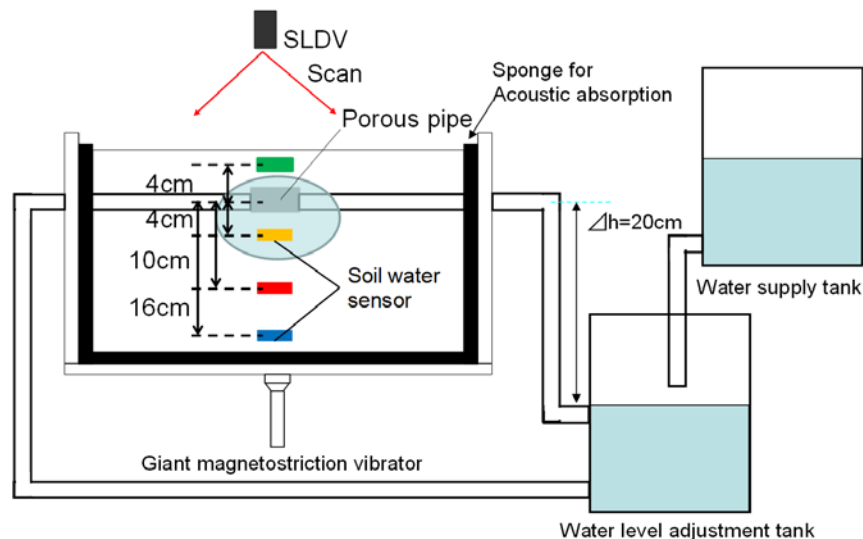


Fig. 8: Experimental setup of water distribution imaging for horizontal direction when using negative pressure irrigation system.

Experiment result

A result of imaging in each time is shown in Fig.9. From this figure, we can confirm that water distribution is temporally changed. Also, a graph with the volume water content which was measured by the soil-water sensor is shown in Fig.10. The graph of average with the volume water content which measured by four sensors and the graph of the average with the propagation velocity which was measured at nine points of the near the porous pipe is shown in Fig.11. We think that the water distribution reaches a base in this time zone because the value isn't changing about 40 minutes later after beginning in the measurement from Fig.11. At the same time, the value isn't changing in the approximately similar time zone about the propagation velocity, too. In other words, we can confirm that the influence

to the propagation velocity when changing the volume water content of the water distribution.

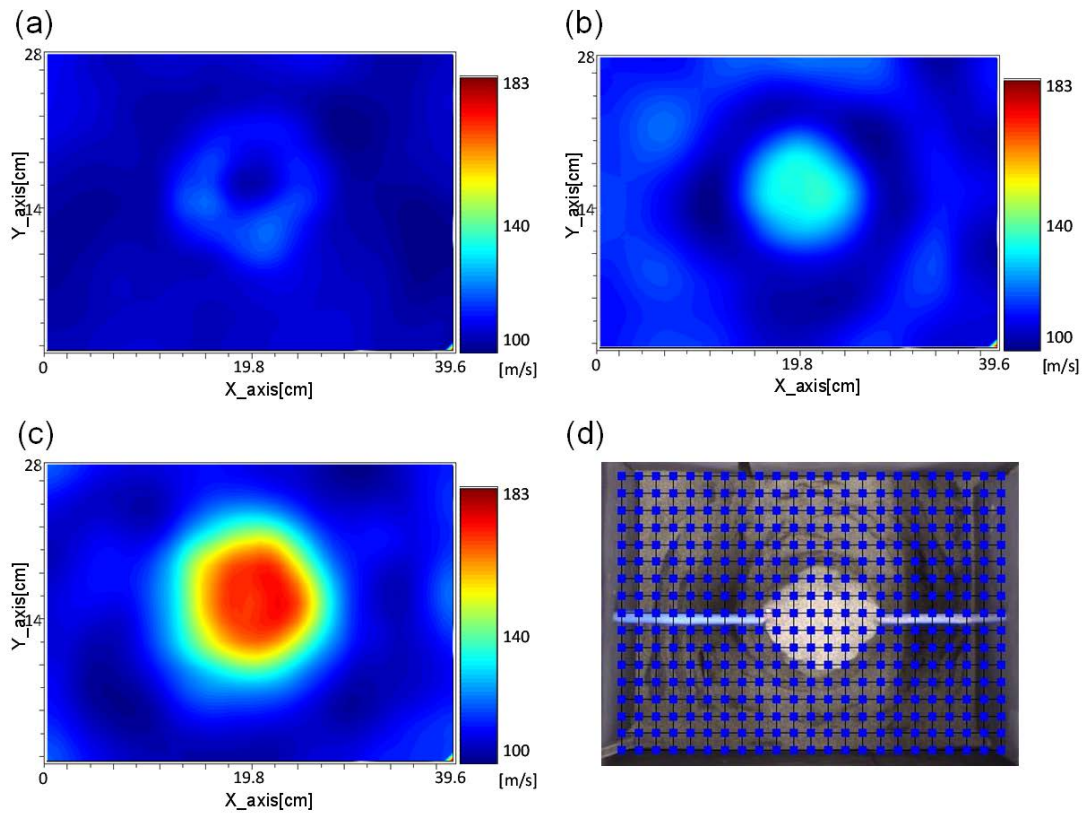


Fig. 9: The results of imaging of sound velocity distribution in each time. (a) 20minutes, (b) 50minutes, (c) 80minutes, (d) scan area photograph after the experiment by CCD camera.

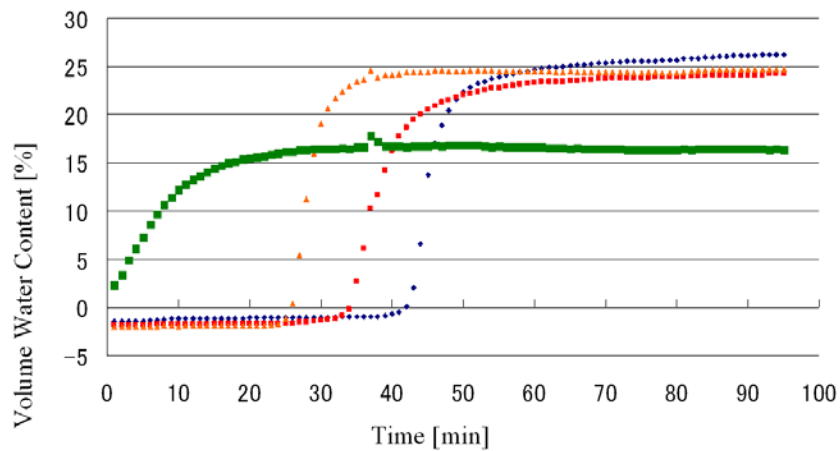


Fig.10: Experimental result of the volume water content which measured by four sensors. Square:4cm, Triangle:4cm, Circular:10cm, Diamond:16cm.

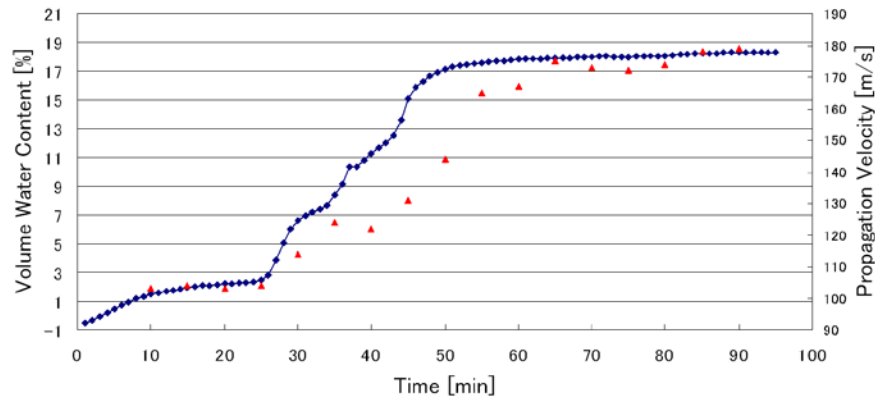


Fig.11: Experimental result of the volume water content and the propagation velocity. Diamond: Volume water content [%] , Triangle: Propagation velocity [m/s].

Water distribution imaging experiment for vertical direction using negative pressure difference irrigation system

Experimental setup

Figure 12 shows an experimental setup for vertical direction when using negative pressure irrigation system. The porous pipe which is made from ceramic is vertically installed in the about 22 cm height from the sand tank base and the level control tank is installed in the position with the low of about 10 cm from the height of the porous pipe. A measurement board with holes was made to measure the real time process when the water in the sand spread in the vertical direction as shown in Fig.12(b). A thin film (polypropylene sheet) of thickness approximately 60 μ m is attached to prevent an outflow of the sand between a measurement board and the sand. The sand vibration can be measured through this film. A flat speaker (FPS Corp. FPS2030M3P1R) is used as a sound source. A sinusoidal burst wave of 4kHz, 5cycles are used as a transmitted wave. Fig.12(c) and (d) show a photograph and schematic of scan area. The scan area of SLDV has 8x10 points, scan point interval is 2.5cm. Soli water sensors are buried at 6, 12 and 18 cm from the bottom of the sand tank. The vibration measurement measured in the interval of 2 minutes and measured until 54 minutes.

Experiment result

A result of imaging in each time is shown in Fig.13. From this figure, we can confirm that vertical water distribution is temporally changed. The propagation speed of sound around the porous pipe begins to rise after irrigation, and we can confirm that high speed area spreads through the vertical direction with time. In addition, As for the lower part becoming the high speed of sound price from the upper part that is near to a porous pipe, it seems with a thing by the gravitational influence.

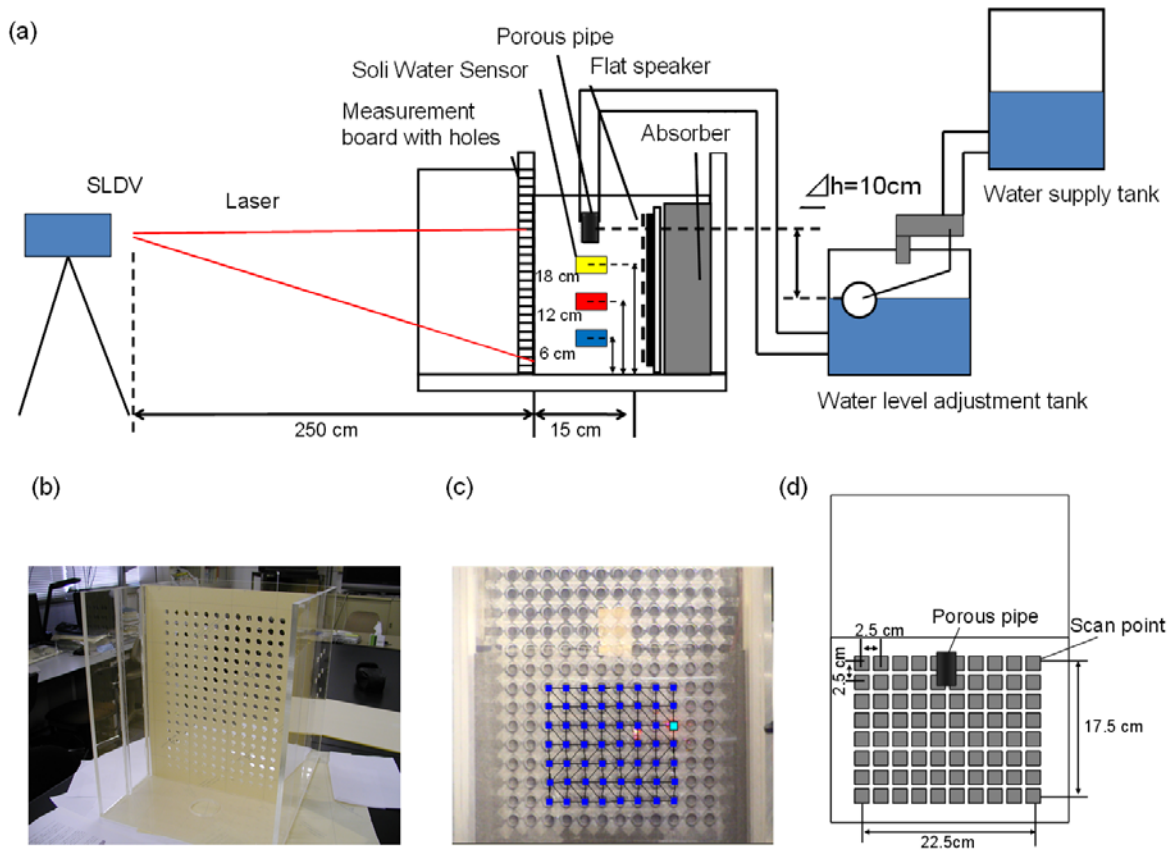


Fig. 12: Experimental setup of water distribution imaging for vertical direction when using negative pressure irrigation system. (a) Experimental setup, (b) acoustic measuring board with holes (acoustic hole:17×12), (c-d) photograph and schematic figure of the scan area.

Also, a graph with the volume water content which was measured by the soil-water sensor is shown in Fig.14(a). The graph of average with the volume water content which measured by three sensors and the graph of the average with the propagation velocity which was measured at nine points of the near the porous pipe is shown in Fig14(b). Compared with these result, it seems that these values change in approximately similar time. As for a propagation speed of sound level of setting position 18cm being lower than others, water distribution of the porous pipe neighborhood is affected by the gravity, and a small thing originates in it as the volume. This became clear after the experiment by removed dry sand, and confirming the whole aspect of the water distribution. Therefore, we can confirm that the influence to the propagation velocity when changing the volume water content of the water distribution.

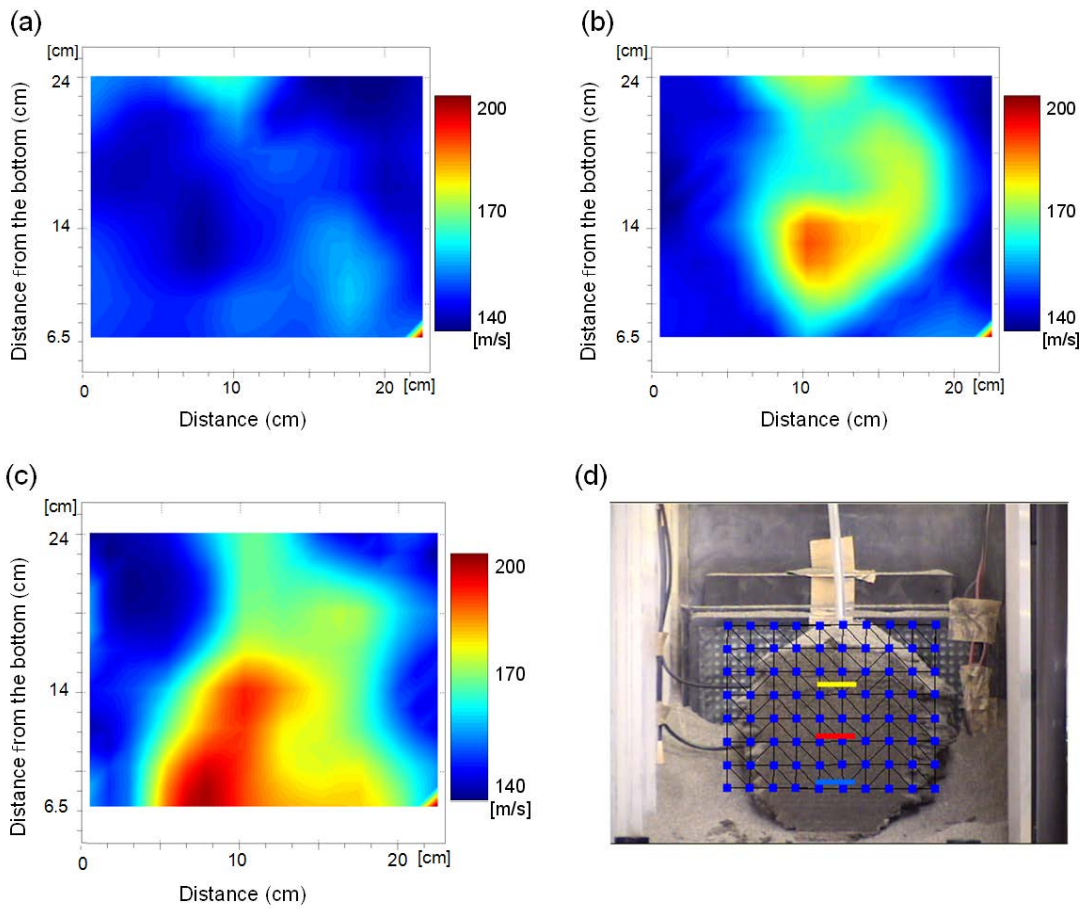


Fig. 13: The results of imaging of sound velocity distribution in each time. (a) 14minutes, (b) 32minutes, (c) 54minutes, (d) scan area photograph after the experiment by CCD camera.

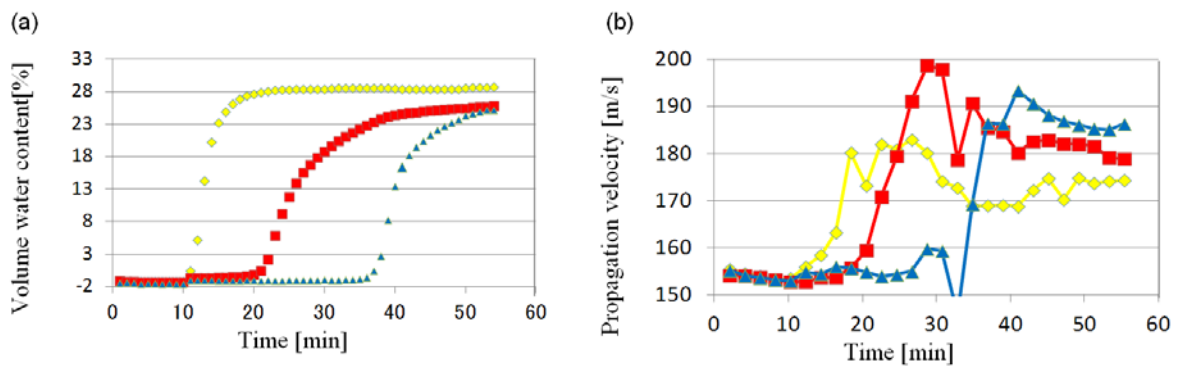


Fig. 14: Experiment result. Yellow circle, red square and blue triangle show the measurement position 18cm, 12cm and 6cm from the bottom of the sand tank. (a) the volume water content which measured by three sensors, (b) estimated propagation velocity near the sensor position.

CONCLUSION

This time, we can confirm that the used vibration velocity distribution image was a very effective imaging method to the water distribution which is in the shallow position near the ground surface. Also, in the experiment which used negative pressure irrigation, we can confirm that it was caught in the water distribution which changes time wise by measuring at both direction of the vibration measurement. In the future, we plan to review the improvement of the estimated precision of the volume water content by the vibration measurement. And, we intend to examine whether our method can apply even in the case that a plant is growing up in soil for gardening.

ACKNOWLEDGMENTS

This work is supported by KAKENHI (No.22658079) and JST, CREST.

REFERENCES

T.Sugimoto , Y.Nakagawa, T.Shirakawa, M.Sano, M.Ohaba and S.Shibusawa, 2011, Basic study of water distribution measurement in sand using sound vibration, Proc. 31th Acoustic Imaging (AI31), p40, 6pages (CD-ROM).

Y.Nakagawa, T.Shirakawa, M.Sano, T.Sugimoto, M.Ohaba and S.Shibusawa, 2011, Basic study of water distribution measurement in soil using a sound vibration, -study on the propagation velocity and the volume water content-, Proc. 4th Asian Conf. Precision Agriculture (ACPA2011), O-30, 4pages (CD-ROM).

T.Sugimoto, Y.Nakagawa, Takshi Shirakawa, M.Sano, M.Ohaba and S.Shibusawa, 2011, Water distribution measurement in soil using sound vibration, Proc. International Congress on Ultrasonics (ICU2011), p112

H.Kawasaki and T.Sugimoto, 2009, Resolution improvement of underground images using pulse compression, Jpn. J. Appl. Phys. 48, 07GC08

T.Abe and T.Sugimoto, 2010, Distinguishing buried objects in extremely shallow underground by frequency response using scanning laser Doppler vibrometer, Jpn. J. Appl. Phys. 49, 07HC15

T.Sugimoto and T.Abe, 2011, Buried object detection method using optimum frequency range in extremely shallow uunderground, Jpn. J. Appl. Phys. 50, 07HC18

Z. Lu and J. M. Sabatier, 2009, Effects of soil water potential and moisture content on sound speed, Soil Science Society of America Journal. 73, 1614